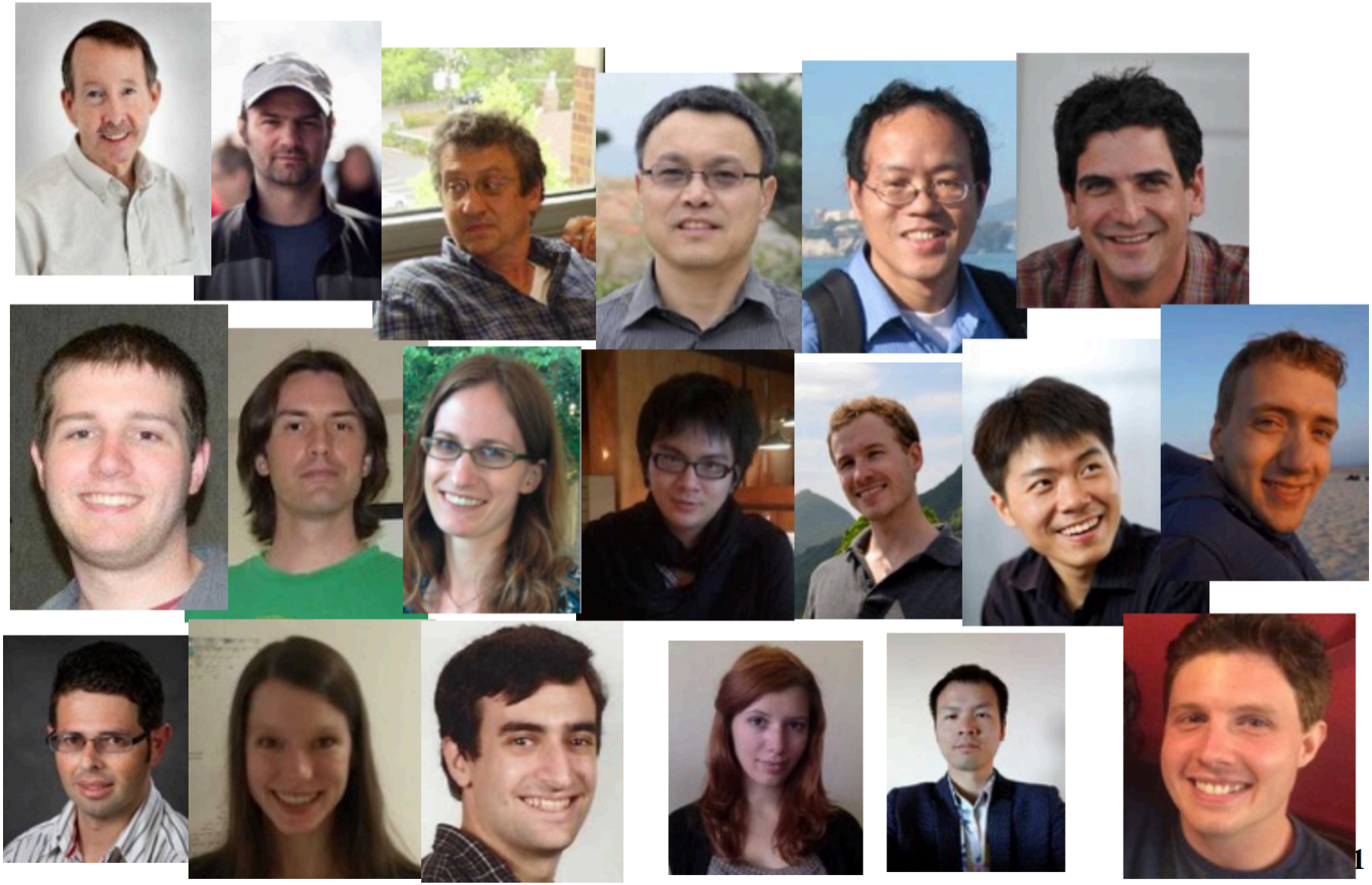
# Program Overview (NSD Theory)

Feng Yuan

Nuclear Science Division
Lawrence Berkeley National Laboratory

U.S. DEPARTMENT OF ENERGY | Office of Science

BERKELEY LAB



# Outline

- NSD-Theory overview (Feng Yuan)
  - Who we are
  - Our goals
  - Recent highlights
  - Near-term plans
  - Long-term plans
- Hadron physics (Feng Yuan)
- UC Connection (Wick Haxton)
- Heavy Ion Theory (Xin-Nian Wang)
- Lattice QCD (Andre Walker-Loud)
- Nuclear Astrophysics (Dan Kasen)

# Staff Members

Senior
- Wick Haxton (Joint UC Berkeley)
- Dan Kasen (Joint UC Berkeley)
- Volker Koch
- Xin-Nian Wang (25% CCNU)
- Feng Yuan

Junior
- Andre Walker-Loud (SciDAC & LDRD)

Long-term visitor
- Romona Vogt (LLNL)

Active Retirees
- Miklos Gyulassy
- Jorgen Randrup

- NAS Member and Fellow of American Acad. Arts and Sciences (Haxton)
- 4 APS Fellows (Haxton, Koch, Wang, Yuan)

# Postdocs and Fellows

Jason Chang (ECA Walker-Loud)

Austin Harris (LDRD)

Amy Nicholson (UCB)

Nils Strothoff (DFG Germany)

Shanshan Cao (50% JET, 50% NSD, now Wayne State)

Robin Dong (Hubble Fellow, now UA)

Francois Fourcart (Einstein Fellow)

Kyle Parfrey (Einstein Fellow)

Huy-Wen Lin (APS Blewett Fellow, now MSU )

# Students

J. Barnes (UC Berkeley, Kasen)
J. Botyanski (UC Berkeley, Kasen)
C. Harris (UC Berkeley, Kasen)
D. Goldstein (UC Berkeley, Kasen)
N. Roth (UC Berkeley, Kasen PhD 2016)
K. McElvain (UC Berkeley, Haxton)
C. Schillaci (UC Berkeley, Haxton, PhD 2016)
A. Schuster (Darmstadt, DAAD fellow, visiting in 2015)
W. Chen (CCNU, Wang)
T. Luo (CCNU, Wang)
Y. He (CCNU, Wang)
D. Brantely (William & Mary, Walker-Loud)
H. Camacho (William & Mary, Walker-Loud)

# Prizes and honors (since 2013)

Feng Yuan, APS Fellow, 2014

Wick Haxton, Simons Fellow, 2016

## Early Career Awards

- Feng Yuan (2010-2015)
- Dan Kasen (2012-2017, UC Berkeley)
- Andre Walker-Loud (2014-2019, William&Mary, LBNL)

# Leadership Roles

Haxton, NAS: Chair, Physics Section (2013- 2016); APS :Executive Board Member 2011-15; Board of Directors, 2015-

Koch, RHIC PAC

Yuan, INT NAC

Committees: various NRC, IUPAP, APS, NSF, DOE, DOE RHIC S&T Reviews, DFG (Germany)

Organizers (organization committee) for major international conferences: CIPANP, Quark Matter, Hard Probes, Strange Quark Matter, Spin Symposium, Town Hall Meetings for 2015 Long Range Plan, …

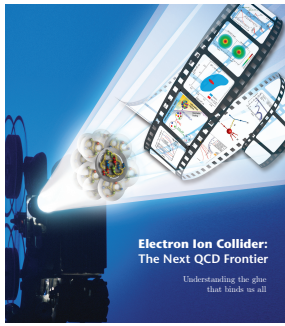
Editorial

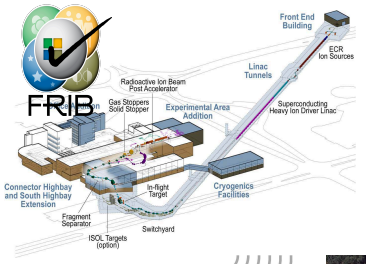
- Haxton, PLB, Ann. Rev. NPS
- Koch, PRL, Divisional Associated Editor (2007-2012)
- Wang, EPJA, IJMP

# Research

- Hadron physics (Yuan)
  - Nucleon Spin, small-x saturation
- Heavy Ion Physics (Koch, Wang)
  - Hard probe, beam energy scan
- Nuclear Many Body (Haxton, Walker-Loud)
  - Nuclear physics using Lattice QCD
- Neutrinos and dark matter (Haxton)
  - Double beta decay
- Nuclear astrophysics (Kasen)
  - Explosive astrophysics, nucleosynthesis, neutron star mergers, supernovae






# 2015 Long Range Plan

**Double Beta Decay**

**EIC**

**Theory Initiative**

- Scientific Computing
- FRIB Theory alliance
- Topical collaborations

QCD and the phases of strongly interacting matter:

- "Probe the inner workings of QGP by resolving its properties at shorter and shorter length scales."
- "Map the phase diagram of QCD"

The origin of heavy elements

Nuclear matrix Elements from Lattice QCD

Hadron structure and nuclear forces from the Lattice

# Topical Collaborations

## 2010-2015

JET Collaboration (PI, Co-Spokesperson, Wang)

Neutrino and Nuclear Astrophysics (Haxton)

## 2016-

- Beam Energy Scan Theory-BEST [Koch, Co-spokesperson]
- The Coordinated Theoretical Approach to Transverse Momentum Dependent Hadron Structure in QCD (TMD) [Yuan]
- Nuclear Theory for Double Beta Decay and Fundamental Symmetries (DBD) [Haxton, Walker-Loud]

# NSF Funding through UC Berkeley

- N3AS (Network for Neutrinos, Nuclear Astrophysics, and Symmetries), focused on postdoctoral training (Berkeley is the lead institution) [Haxton]
- JETSCAPE Collaboration (Jet Energy-Loss Tomography with a Statistically and Computationally Advanced Program Envelope) [Wang]

# Exascale Computing Project
## nuclear astrophysics application

*"Exascale Models of Stellar Explosions: Quintessencial multi-physics simulations"*

**LBL lead:** Kasen (PI), Haxton, Almgren, Zhang (CRD)
**Partners:** ORNL, ANL, Stonybrook

Seed funding started10/2016
Plan to ramp up to full support ($2.5M/yr) by 2018
Also upcoming: SciDAC collaboration

# Publications

## 178 publications, 19 Letters, 8 Reviews, 141 talks

### Neutrino physics: What makes the Sun shine

**Wick Haxton**

*Nature* **512**, 378–380 (28 August 2014) | doi:10.1038/512378a
Published online 27 August 2014

### No signature of ejecta interaction with a stellar companion in three type Ia supernovae

**Rob P. Olling, Richard Mushotzky, Edward J. Shaya, Armin Rest, Peter M. Garnavich, Brad E. Tucker, Daniel Kasen, Steve Margheim & Alexei V. Filippenko**

**Affiliations** | **Contributions** | **Corresponding author**

*Nature* **521**, 332–335 (21 May 2015) | doi:10.1038/nature14455
Received 16 January 2015 | Accepted 23 March 2015 | Published online 01 January 2015

PHYSICAL REVIEW LETTERS week ending 5 APRIL 2013

### chanisms for the Synthesis of Rare $^9$Be in Early Supernovae

jee,[1,*] Yong-Zhong Qian,[2,†] W. C. Haxton,[1,‡] and Alexander Heger[3,§]

(2014) PHYSICAL REVIEW LETTERS week ending 14 MARCH 2014

### to-Leading Order QCD Factorization for Semi-Inclusive Deep Inelastic Scattering at Twist 4

Zhong-Bo Kang,[1] Enke Wang,[2] Xin-Nian Wang,[2,3] and Hongxi Xing[1,2,4]

1 (2016) PHYSICAL REVIEW LETTERS week ending 20 MAY 2016

### he Small-$x$ Gluon Tomography in Correlated Hard Diffractive Dijet Production in Deep Inelastic Scattering

Yoshitaka Hatta,[1] Bo-Wen Xiao,[2] and Feng Yuan[3]

PHYSICAL REVIEW LETTERS week ending 22 FEBRUARY 2013

### ov Resummation in the Small-$x$ Saturation Formalism

A. H. Mueller,[1] Bo-Wen Xiao,[2,3] and Feng Yuan[4]

PHYSICAL REVIEW LETTERS week ending 9 AUGUST 201

### ium Modification of $\gamma$ Jets in High-Energy Heavy-Ion Collisions

Xin-Nian Wang[1,2] and Yan Zhu[3]

5) PHYSICAL REVIEW LETTERS week ending 22 MAY 201

### tical Correlations for Higgs Boson Plus High $P_T$ Jet Production at Hadron Colliders

Peng Sun,[1] C.-P. Yuan,[2] and Feng Yuan[1]

PHYSICAL REVIEW LETTERS week end 28 JUNE 2

### Four-Dimensional Monopoles in the Relativistic Chiral Kinetic Equatio

iunn-Wei Chen,[1] Shi Pu,[1,2] Qun Wang,[2] and Xin-Nian Wang[3,4]

2001 (2014) PHYSICAL REVIEW LETTERS week ending 5 DECEMBER

### Soft Gluon Resummations in Dijet Azimuthal Angular Correlations in Hadronic Collisions

Peng Sun,[1] C.-P. Yuan,[2] and Feng Yuan[1]

PRL 117, 072002 (2016) PHYSICAL REVIEW LETTERS week e 12 AUGU

### Massive Photons: An Infrared Regularization Scheme for Lattice QCD + QED

Michael G. Endres,[1,*] Andrea Shindler,[2,†] Brian C. Tiburzi,[3,4,5,‡] and André Walker-Loud[6,7,8,§]

ScienceDaily®

Science News

*from research organizations*

# Exotic matter: A closer look at the perfect fluid sheds light on what happened microseconds after the Big Bang

*Date:* October 2, 2014

*Source:* DOE/Lawrence Berkeley National Laboratory

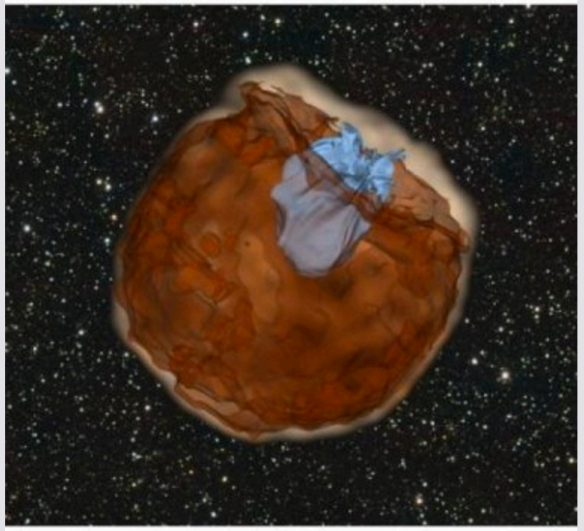
*Summary:* By combining data from two high-energy accelerators, nuclear scientist
the measurement of a remarkable property of exotic matter known as q
plasma. The findings reveal new aspects of the ultra-hot, 'perfect fluid'
to the state of the young universe just microseconds after the Big Bang

# Supernova collides with its companion star

*Date:* May 20, 2015

*Source:* California Institute of Technology

*Summary:* Type Ia supernovae, one of the most dazzling phenomena in th
produced when small dense stars called white dwarfs explode
At their peak, these supernovae can outshine an entire galaxy.
supernovae of this kind were found in the last decades, the pro
dwarf becomes one has been unclear.



This is a still from a simulation of a Type Ia supernova. In the simulation, a Type Ia supernova explodes (dark brown color). The supernova material is ejected outwards at a velocity of about 10,000 km/s. The ejected material slams into its companion star (light blue). Such a violent collision produces an ultraviolet pulse which is emitted from the conical hole carved out by the companion star.

*Credit: Courtesy of Dan Kasen*

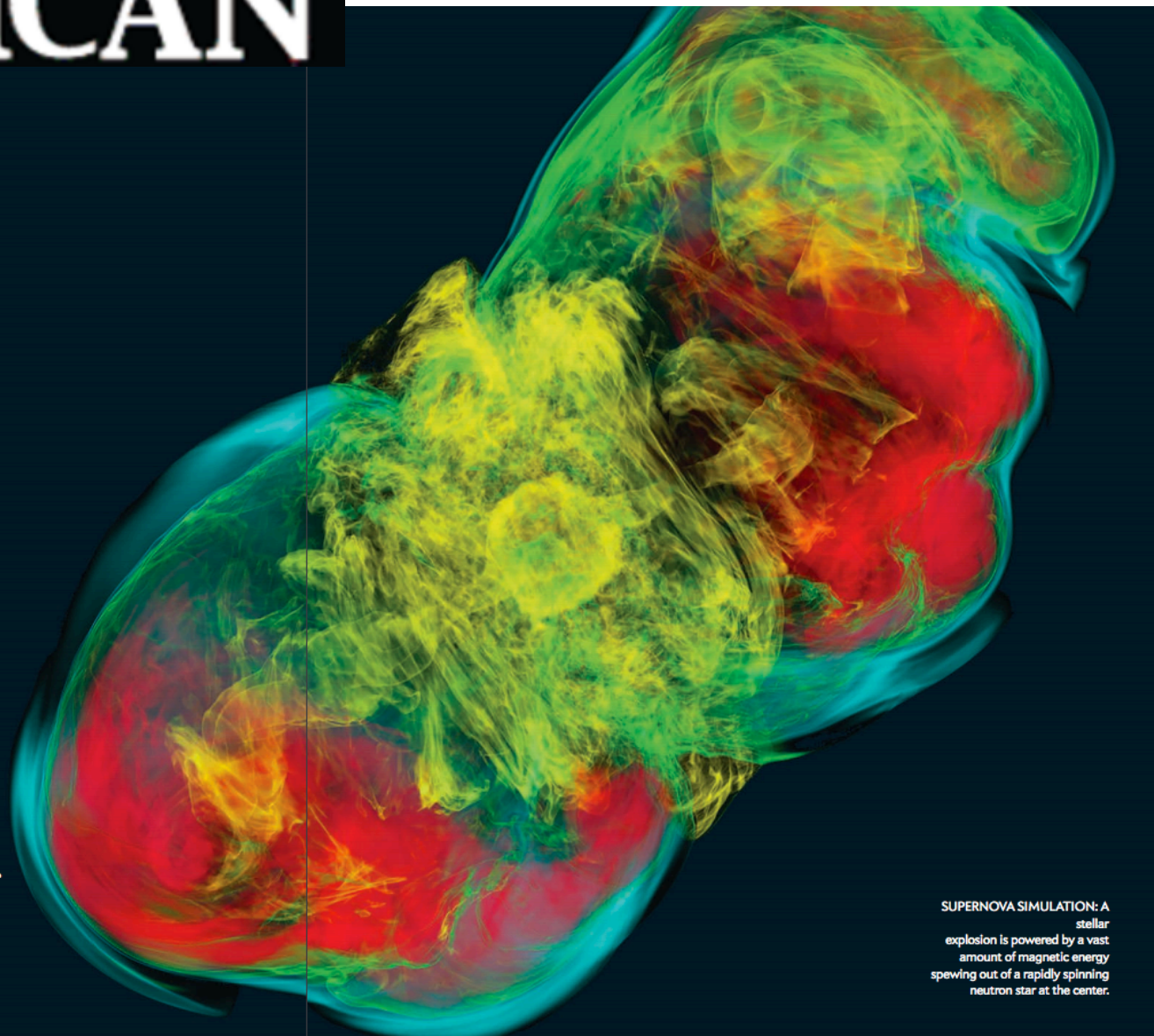
SCIENTIFIC AMERICAN

**Daniel Kasen** is an astrophysicist at the University of California, Berkeley, and at Lawrence Berkeley National Laboratory. His research focuses on developing new theoretical and computer models to explain the many types of stellar explosions in the universe.

# STELLAR FIREWORKS

**Every year thousands of exploding stars appear in a bizarre assortment of forms. Astronomers want to know what makes them go boom**

*By Daniel Kasen*



SUPERNOVA SIMULATION: A stellar explosion is powered by a vast amount of magnetic energy spewing out of a rapidly spinning neutron star at the center.

# Scientific Goals

## Leadership in nuclear theory research frontier

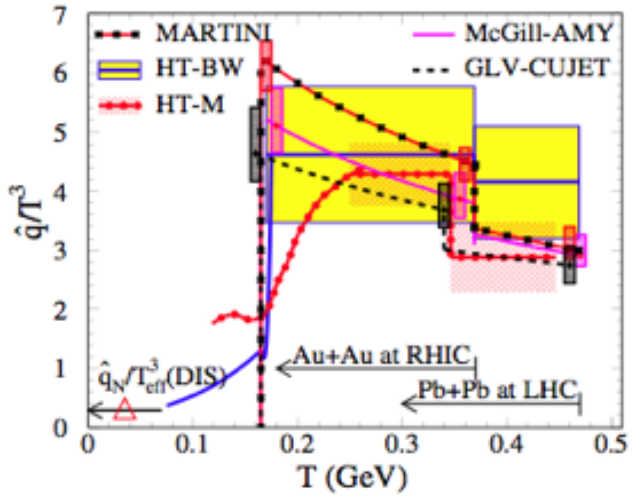
- Hadron physics (RHIC and JLab), future EIC
- Heavy ion physics
  - QCD Critical point, Beam energy scan at RHIC
  - Hard probe of hot QCD matter
- Nuclear physics using Lattice QCD
- Nuclear astrophysics (FRIB connection)

## Support the nuclear science program in US

- Realizations of major investments from the Long Range Plan Recommendations
  - Double beta decay
  - Electron-Ion Collider

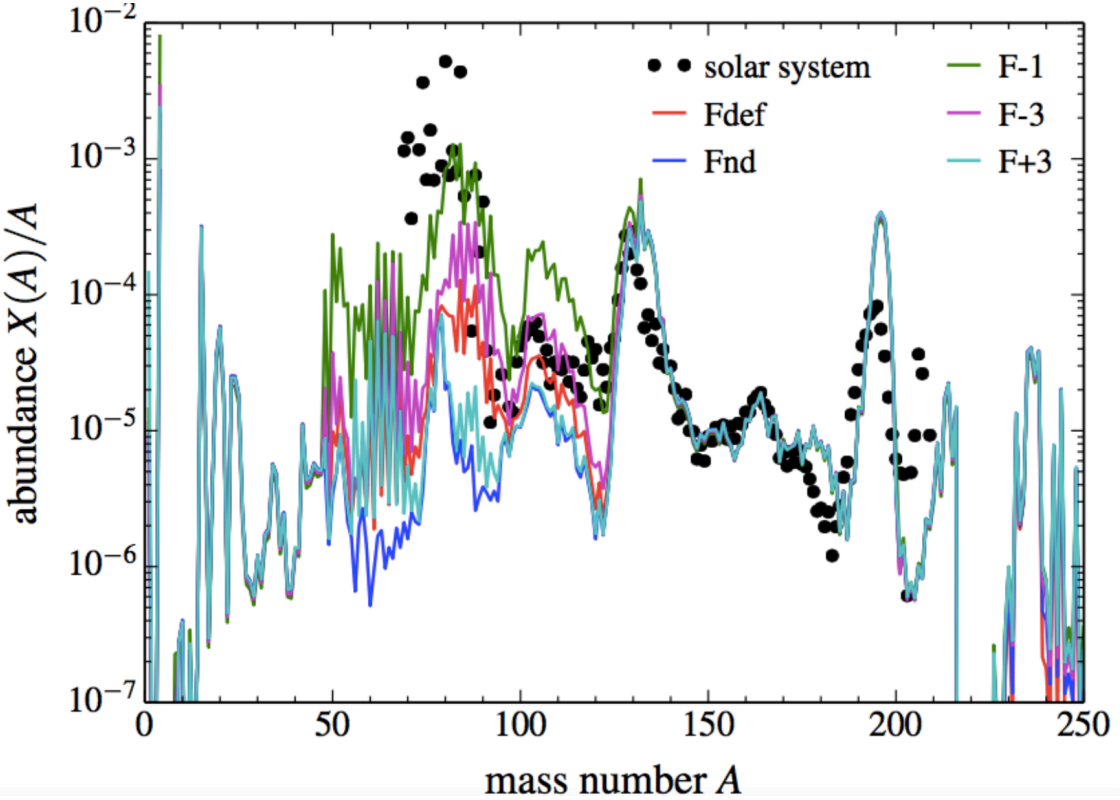
# Recent Highlights

- The effective field theory of dark matter direct detection (Haxton et al., 2013)
  - The most general nucleon-level effective field theory, six independent nuclear responses
- Jet transport coefficient determined by the JET collaboration (Wang)



# Recent Highlights

- Nucleosynthesis (Kasen)
  - origin of heavy element production pathways for r-process, sensitivity to nuclear inputs



# Program evolution

- NSD-theory group used to be focusing on relativistic heavy ion collision physics
- With recent hiring, the program has expanded to cover all major nuclear science research
  - Yuan (2007), Haxton (2009), Kasen (2010), Walker-Loud (2014)

- Looking forward: challenges and opportunities
  - Continue the support for current research activities
  - New funding opportunities will help us to achieve the near and future goals
    - Topical collaborations, ECP, JETSCAPE, N3AS, SciDAC
  - Capitalize on the strong connections to the UC Berkeley

# Exciting current projects

- Probe the novel partonic structure of nucleon/nucleus
- Beam Energy Scan Theory framework
- Hard probe for the quark-gluon-plasma
- Simulate heavy element production in supernovae and neutron star mergers
- Lattice QCD calculations for neutrinoless double beta decay, permanent EDMs in large nuclei, nucleon and nuclear structure

# Goals in near term and midterm future

- EIC-theory initiatives, connection between EIC and heavy ion programs
- Comprehensive studies of QGP with hard probes
- Build the rigorous theoretical framework for beam energy scan program at RHIC
- Couple Harmonic Oscillator Based Effective Theory and lattice input for nuclear structure physics
- Connecting neutron star merger r-process and equation of state to gravitational wave and electromagnetic detections

# Long-Term Plans

- Make the LBNL Nuclear Theory Group into one of the nation's premier centers, focused on the highest priority research goals of our field

- Answer the following scientific questions:
  - Is there critical point in QCD? How to "prove it" or "exclude it" rigorously?
  - What are the properties of sQGP?
  - Will EIC solve the proton spin puzzle finally?
  - Can we predict properties of nuclei from lattice results?
  - Can we connect the structure of nuclei near the dripline to the properties of the r-process site?…

# Strategy

Take full advantage of the assets we have at Berkeley

- Broad and excellent experimental program at LBNL
- Strengthen the UC Berkeley connections
  - NSF funding and postdocs/strudents,
  - Possibly new hiring
- Play important roles in all three topical collaborations
- EIC-theory initiative (current LDRD)
- Strengthen the computational efforts
  - Lattice QCD (continue with the SciDAC)
  - Computational astrophysics (SciDAC and ECP)

# Synergies

- Close contact with experimental programs at Berkeley and elsewhere
  - Heavy ion / Spin physics
  - Neutrino physics / Weak interactions
  - Astrophysics and nuclear structure
- Close contact with LBNL Computational Research Division (CRD), NERSC, and LLNL lattice group
  - Cold Lattice QCD
  - Harmonic Oscillator Effective Theory
  - Computational astrophysics

# LDRD

- Computational Nuclear Physics Code Development for Fundamental Physics/Astrophysics, Supporting FRIB (Haxton, Kasen, 2014-2017)

  Scientific outcomes
  - seeded the early work on late-time evolution of SNe that will now be continued under ECP
  - improved LQCD calculations of phase shifts beyond s-wave, and their use in effective theory
  - two-orders-of-magnitude advancement of the SciDAC II shell model code Bigstick

- Theoretical Challenges for Electron-Ion Collider Physics (Gyulassy, Wang, Yuan, 2017-)


Thanks!